Deformetrica: a software for statistical analysis of anatomical shapes

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Introduction

We present Deformetrica, which is a C++ software for the statistical analysis of 2D and 3D shape data. Data can be surface meshes, polygonal lines, labeled points or unstructured point sets. It is therefore of particular interest for the statistical analysis of multi-object anatomical data including surfaces meshes of cortical or sub-cortical structures and white matter fiber tracts.

Deformetrica comes with two applications: registration and atlas construction. The former computes an optimal deformation between two multi-objects. The latter computes an average shape of a collection of multi-objects, called template, and its deformations to each sample in the collection. Deformations are parametrized by a small number of 2D or 3D vectors, which can be used then for statistical purposes.

It is publicly available at http://www.deformetrica.org.

Methods

The considered deformations are diffeomorphisms of the entire 2D/3D ambient space, which then deform meshes embedded into this space. The diffeomorphism is built as the endpoint of a geodesic path on certain Riemannian manifold. It is fully determined by the initial velocity, which is parameterized by a set of momentum vectors attached at optimally located control points[2].

The use of the metric on currents[6] or varifolds[1] allows to measure dissimilarity between surface or curve meshes without the need to establish point correspondence across meshes. These metrics enable to be robust with respect to changes in topology between meshes, small holes, spikes, or irregular sampling. The method may deal with a hierarchy of annotated structures. For instance, the dissimilarity may be computed between sets of curves for white matter fiber bundles or between individual curves for sulcal lines.

Registration and atlas construction methods are solved thanks to the minimization of a cost function using one of two gradient descent methods namely adaptive step-size method or FISTA. For atlas construction, the user needs to specify the topology of the template shapes by providing a prototype set of meshes. The position of the control points are automatically adjusted to the most variable parts of the template shape as illustrated in Figure 1.

Core parts of Deformetrica benefits from CUDA acceleration.

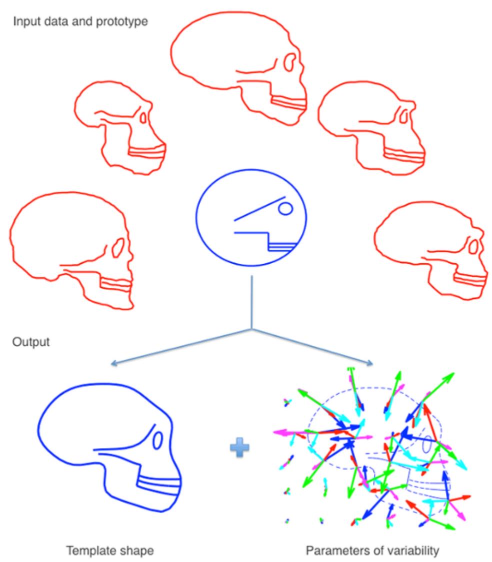

Figure 1 **-** Example of an atlas construction build from a set of 5 skull profiles (2D). We need to give the algorithm a prototype template, which gives the topology (number of vertices and connectivity) of the template that will be estimated.

Results

We present three examples of use of Deformetrica in neuroimaging studies:

- study of variations in anatomical connectivity in patients with Gilles de la Tourette syndrome[4] in Figure 2.
- classification between patients with Alzheimers disease, mild cognitive impairment and elderly controls based on the shape of their sub-cortical structures[5] in Figure 3.
- registration of histological atlas to pre-operative MRI of Parkinsonian patients for surgical planning in Deep Brain Stimulation[3] in Figure 4.

Conclusions

Deformetrica opens up new possibilities for neuroimaging studies based on segmented structures from structural and diffusion images. It is therefore complementary to the usual softwares in the community.

References

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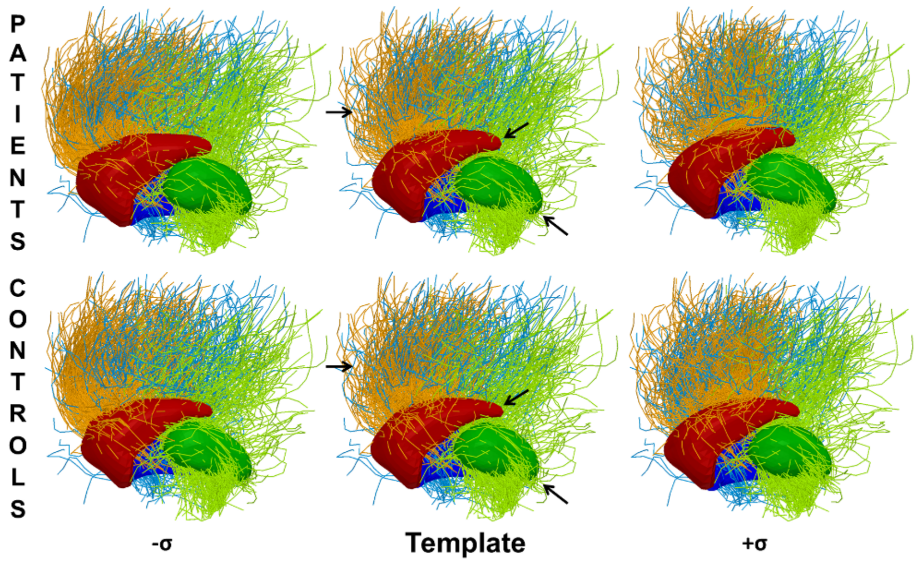

Figure 2 - Comparison of the main morphometric variations between the population of controls and patients. Both rows show the first mode of PCA based on the covariance matrix of the deformation parameters. Arrows indicate the locations showing the greatest variability.

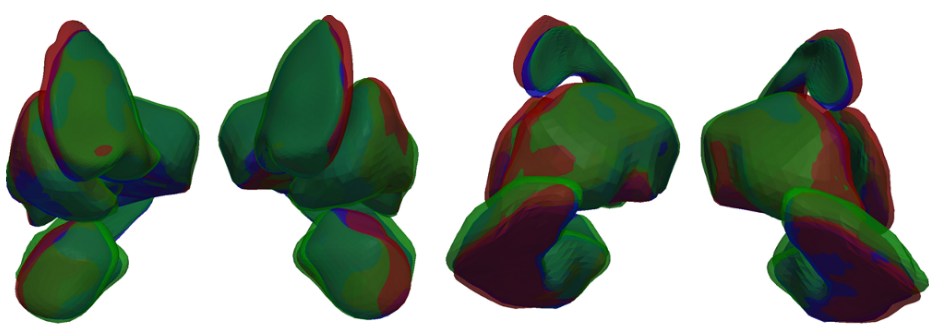

Figure 3 – Superimposition of 3 template shapes of 12 deep brain structures for patients with Alzheimer's disease (red), mild cognitive impairments (blue) and control subjects (green). Theses atlas encode different patterns such as the shift of the caudate nucleus due to the ventricular enlargement and the hippocampal atrophy

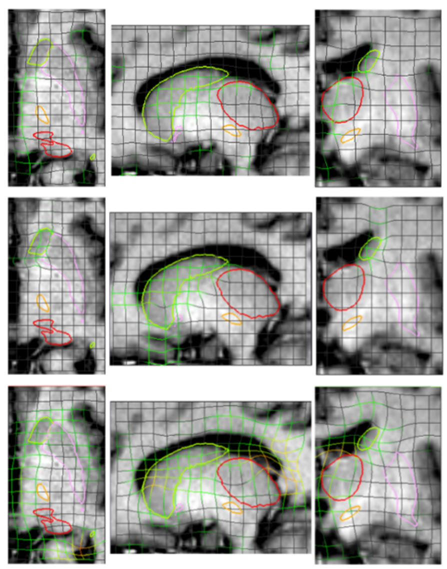

Figure 4 - Deformation fields produced by the registration of a 3D histological atlas of the basal ganglia into patient data for Deep Brain Stimulation planning. From top to bottom: deformation field obtained using iconic information alone, geometric information alone, and combined iconic-geometric information respectively.